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Table 1. Catalog of HDF Classifications

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
3-296	12 36 57	62 12 59	1722	961	21.02	-0.98	0.74	0.70	0.18	0.35	S	8:	merger? [k]
2-135	12 36 49	62 13 15	322	619	21.12	-0.07	1.35	1.16	0.18	0.41	S	4	multi-nucleus spiral?
3-426	12 36 51	62 12 21	427	1478	21.13	0.21	1.28	1.03	0.08	0.61	E	2	S0 / Sa
4-312	12 36 43	62 12 41	375	1134	21.29	0.43	2.27	2.03	0.13	0.68	E	0	E3 [R]
2-280	12 36 49	62 14 07	1572	1126	21.39	-0.47	1.03	1.35	0.13	0.55	E	3	Sa [R]
4-280	12 36 46	62 11 52	1782	1089	21.49	0.94	1.89	1.39	0.11	0.74	E	0	E1
3-350	12 36 55	62 12 46	1300	1165	21.56	-0.26	1.36	1.67	0.09	0.49	S	4	Sb pec [y]
3-90	12 36 49	62 12 57	466	472	21.56	-0.35	1.24	1.17	0.23	0.55	S	3	Sa pec
2-403	12 36 52	62 13 55	1058	1528	21.57	-0.40	0.35	0.63	0.41	0.32	P	8	multiple merger [f,B]
2-134	12 36 49	62 13 14	306	543	21.75	-0.56	0.83	0.73	0.07	0.62	E	0	E3
4-672	12 36 41	62 11 42	1668	2031	21.75	-0.45	1.79	1.52	0.19	0.45	S	3	Sa [g,R]
4-665	12 36 39	62 12 20	612	2026	21.80	-1.00	0.95	1.07	0.21	0.42	S	8?	merger?
4-660	12 36 40	62 12 08	965	1982	21.86	0.20	1.39	1.79	0.05	0.60	E	0	E1
4-147	12 36 45	62 12 46	479	611	21.88	-0.05	1.61	1.85	0.03	0.60	E	-1	E0 (or star)
4-487	12 36 43	62 11 49	1631	1659	21.99	-0.22	1.29	1.78	0.06	0.40	S	4	Sb [R]
3-131	12 36 55	62 13 11	1539	564	21.99	-0.62	2.00	2.11	0.06	0.52	E	0	E0
4-56	12 36 48	62 12 21	1264	385	22.02	-1.02	0.54	1.11	0.16	0.31	S	8	mrg., 5 components [f,v]
3-512	12 36 57	62 12 27	1368	1733	22.02	-0.74	1.20	1.08	0.18	0.32	P	4	1-armed S or merger [x,y]
2-482	12 36 53	62 13 55	962	1737	22.03	-0.45	0.86	1.40	0.10	0.38	S	4	pec
3-543	12 36 56	62 12 21	1220	1825	22.08	-0.64	2.11	2.04	0.05	0.53	E	0	E0
4-18	12 36 49	62 12 17	1438	248	22.08	-0.19	1.53	1.95	0.17	0.44	S	4?	Disk w/ 3 knots [R]
3-283	12 36 57	62 13 00	1851	996	22.14	-0.79	0.75	0.47	0.12	0.39	S	3:	Sa + knot, or merger
3-128	12 36 50	62 12 56	639	593	22.15	-0.71	0.95	0.65	0.10	0.49	S	8?	merger?
4-105	12 36 48	62 12 14	1380	588	22.22	-0.82	0.74	1.39	0.10	0.21	P	5	S(B)c t [x,y]
4-357	12 36 43	62 12 18	961	1292	22.24	-1.02	0.71	1.10	0.07	0.54	E	3	Sa pec
2-553	12 36 55	62 13 55	841	1958	22.24	-0.61	0.62	1.18	0.13	0.28	S	4?	nucleated Ir? [x,y]
2-86	12 36 48	62 13 21	525	521	22.27	-1.10	0.50	0.92	0.12	0.27	S	8	merger (proto-spiral?) [a]
4-683	12 36 38	62 12 31	302	2004	22.27	-0.63	1.88	1.51	0.18	0.33	S	2?	S0?
2-164	12 36 50	62 13 18	341	769	22.27	-0.44	1.61	1.83	0.10	0.32	S	4	distorted spiral [R]
4-455	12 36 44	62 11 43	1858	1510	22.28	-0.77	0.61	1.17	0.26	0.21	P	8	merger [f,x,y]
3-153	12 36 57	62 13 15	1937	625	22.32	-1.10	0.39	0.90	0.39	0.29	P	8	merger [f]
4-137	12 36 47	62 12 30	923	578	22.32	-0.90	0.94	0.70	0.16	0.48	S	3	Sab pec [b]
2-116	12 36 48	62 13 30	755	589	22.34	-0.70	0.71	1.32	0.19	0.32	P	8?	merger?
2-85	12 36 48	62 13 20	510	522	22.37	-1.06	0.74	1.25	0.13	0.23	P	8	Merger (proto-spiral?) [a,x,y]
3-376	12 36 53	62 12 35	847	1275	22.41	-0.76	0.92	0.93	0.19	0.43	S	2?	S0 pec?
4-162	12 36 48	62 11 49	2034	674	22.47	-0.71	1.01	1.51	0.08	0.49	E	3	Sa pec
2-301	12 36 49	62 14 16	1759	1254	22.55	0.01	0.39	0.46	0.25	0.18	P	8	multiple, mergers [B]
4-466	12 36 43	62 11 52	1563	1588	22.56	-0.73	0.29	0.64	0.07	0.64	E	0?	E3 pec?
2-592	12 36 55	62 14 03	1054	2047	22.57	-0.41	1.24	1.16	0.07	0.34	S	4	2 nuc. in disk, merger?
4-348	12 36 44	62 12 01	1461	1274	22.58	-0.97	1.23	0.94	0.06	0.33	S	4	Sb pec
2-383	12 36 51	62 14 02	1260	1466	22.62	-0.74	1.05	1.05	0.21	0.43	S	1?	S0? pec [b]
2-139	12 36 46	62 14 08	1801	658	22.66	-0.64	0.55	0.46	0.26	0.57	E	0	E3 [g]
3-312	12 36 55	62 12 49	1347	1089	22.69	-0.62	0.64	1.29	0.14	0.26	P	8	merger [f]
2-352	12 36 50	62 14 19	1785	1383	22.71	-0.97	0.64	1.17	0.09	0.30	P	4	1-arm S + cpct. comp. [b,ac]
4-627	12 36 40	62 12 04	1120	1890	22.72	-0.86	0.50	1.09	0.39	0.30	P	7	tad. gal., mult. nuc.
2-278	12 36 51	62 13 34	603	1172	22.74	-0.58	0.83	1.41	0.04	0.35	S	0:	E1? [R]
3-475	12 36 52	62 12 21	577	1557	22.74	-1.00	1.00	0.71	0.09	0.62	E	0	E4

Table 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
4-341	12 36 45	62 11 54	1664	1250	22.77	1.38	1.00	0.60	0.36	0.31	P	8	merger, in group [R]
4-585	12 36 39	62 12 28	461	1813	22.78	-0.25	0.54	0.52	0.15	0.31	P	8	S + St, merger
3-174	12 36 50	62 12 52	599	696	22.79	-0.62	1.16	1.06	0.07	0.20	S	8?	merger? [a,x,y]
3-294	12 36 56	62 13 01	1678	888	22.80	-0.75	0.56	1.29	0.06	0.53	E	0	E0 [R]
4-626	12 36 40	62 12 06	1078	1849	22.81	0.42	0.63	0.65	0.20	0.58	E	3	Sa pec [g]
2-121	12 36 49	62 13 19	424	609	22.84	-0.73	0.50	0.89	0.16	0.49	S	4?	Sbt?
2-445	12 36 52	62 14 05	1290	1648	22.85	-0.75	1.00	1.17	0.45	0.34	P	8	multiple merger [ae]
4-258	12 36 44	62 12 40	489	985	22.87	-1.04	0.54	1.21	0.14	0.26	P	8	merger [f]
3-629	12 36 56	62 12 11	1076	2059	22.87	-0.62	0.98	0.66	0.12	0.35	S	3	Sab pec
2-220	12 36 49	62 13 52	1170	1042	22.91	-0.95	0.53	1.20	0.31	0.21	P	8	multi-component mrg. [x]
3-666	12 36 58	62 12 16	1428	2078	22.91	-0.93	0.32	0.86	0.09	0.48	E	1	E3 / Sa
4-85	12 36 47	62 12 32	907	476	22.92	-0.77	0.77	1.28	0.06	0.47	E	3	Sa
3-581	12 36 58	62 12 23	1559	1927	22.92	-1.14	0.61	0.87	0.08	0.51	E	3	Sa pec
2-84	12 36 48	62 13 19	493	453	22.93	0.20	1.43	1.13	0.04	0.54	E	0	E3
2-416	12 36 51	62 14 21	1763	1572	22.93	-0.92	0.92	0.70	0.12	0.31	S	4	peculiar one-arm S? [ad]
4-286	12 36 46	62 11 45	1973	1088	22.94	-1.13	0.16	0.68	0.34	0.22	P	8?	merger? [a,x,y]
4-132	12 36 49	62 11 56	1889	594	22.96	-1.00	0.20	0.66	0.06	0.64	E	0	E2
4-510	12 36 41	62 12 15	890	1670	22.97	0.74	2.14	2.02	0.12	0.64	E	0	E3 [R]
2-520	12 36 55	62 13 32	252	1814	23.02	-0.52	0.50	1.08	0.10	0.28	S	4	S? pec [y]
4-340	12 36 45	62 11 55	1627	1248	23.04	0.13	2.02	2.02	0.12	0.53	E	0	E1, in group
2-535	12 36 53	62 14 18	1528	1901	23.05	-0.58	1.07	0.95	0.06	0.41	S	2	S0 pec [b]
2-243	12 36 48	62 14 17	1882	1036	23.06	0.35	0.46	0.55	0.30	0.52	S	0	E3
3-188	12 36 55	62 13 03	1415	718	23.08	-0.11	2.25	2.00	0.17	0.63	E	0	E3 [R]
3-598	12 36 52	62 12 03	378	1964	23.09	2.08	1.31	0.95	0.20	0.71	E	0	E1 t, in cpt. group
3-607	12 36 59	62 12 23	1676	1979	23.11	-1.17	0.92	0.76	0.26	0.26	P	4?	S? [s]
2-140	12 36 46	62 14 08	1812	638	23.13	-1.05	0.45	1.22	0.18	0.50	P	4	S, near E3 [R]
3-651	12 36 52	62 11 58	218	2065	23.13	-0.86	1.19	0.82	0.10	0.30	S	4	S pec [a]
2-187	12 36 47	62 14 14	1908	828	23.14	-0.35	1.29	1.37	0.14	0.43	S	0	E4 pec + star [R]
3-606	12 36 59	62 12 22	1695	2001	23.14	-1.22	0.71	1.00	0.25	0.26	E	3	Sa
2-99	12 36 47	62 13 43	1166	501	23.16	-0.49	0.31	0.66	0.16	0.64	E	0	E0 t
3-365	12 36 50	62 12 26	195	1234	23.18	-0.85	0.30	0.90	0.27	0.39	S	3:	? [h]
3-169	12 36 49	62 12 46	246	696	23.19	-0.99	0.94	0.78	0.18	0.35	S	7	pec
3-367	12 36 50	62 12 27	209	1218	23.21	0.10	0.46	0.53	0.26	0.38	S	7	tadpole galaxy [l]
2-74	12 36 47	62 13 32	874	425	23.21	-1.13	0.58	1.35	0.07	0.24	S	4?	clumpy, has nucleus [x,y]
2-299	12 36 49	62 14 15	1739	1260	23.24	0.20	0.50	0.69	0.25	0.24	P	8	multiple, mergers [B]
2-127	12 36 48	62 13 24	579	586	23.24	-0.80	0.37	0.55	0.28	0.38	E	6?	E0 t + Ir? [z]
4-270	12 36 44	62 12 27	819	1038	23.26	0.27	0.45	0.69	0.16	0.49	S	4?	merger or Sa pec [b]
4-282	12 36 45	62 12 02	1511	1080	23.27	-1.08	0.93	1.11	0.21	0.36	S	4?	pec, three nuclei
3-111	12 36 51	62 13 00	776	528	23.28	-0.64	0.60	0.52	0.13	0.23	P	6	Ir
2-585	12 36 55	62 14 01	984	2034	23.29	-0.91	0.92	0.98	0.13	0.33	S	4	disk [b,h]
3-481	12 36 53	62 12 23	715	1565	23.31	-0.78	0.24	0.33	0.30	0.40	S	8	merger [f,B]
3-589	12 36 59	62 12 26	1832	1950	23.35	-0.09	0.37	0.39	0.17	0.25	P	8	merger [f,B]
4-625	12 36 41	62 12 03	1149	1825	23.36	1.74	0.95	0.53	0.29	0.40	P	0	E1, in a group
3-297	12 36 56	62 12 58	1646	967	23.37	-0.70	1.20	1.01	0.14	0.41	S	2	S0 pec
4-678	12 36 39	62 12 12	825	2032	23.40	-0.87	1.20	1.77	0.11	0.57	E	0	E1 [vR]
2-380	12 36 52	62 13 46	810	1458	23.41	-0.03	0.32	0.45	0.32	0.30	P	8	multiple merger [f,vB]
2-96	12 36 49	62 13 12	296	474	23.42	-0.86	0.37	1.01	0.20	0.58	E	3	Sa
3-60	12 36 54	62 13 14	1501	449	23.43	-1.04	0.87	0.79	0.08	0.39	S	8?	Ir? or merger

Table 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
2-313	12 36 53	62 13 24	266	1269	23.44	-0.32	0.26	0.44	0.27	0.49	S	7	St + inter. comp. [B]
4-654	12 36 39	62 12 14	789	1960	23.45	-0.15	1.49	1.79	0.12	0.35	S	4	disk [b,w,R]
3-135	12 36 55	62 13 11	1490	539	23.50	-1.00	0.74	0.56	0.11	0.41	P	8?	?
3-148	12 36 49	62 12 49	351	664	23.52	-0.82	0.97	1.20	0.05	0.48	E	-1	E0 or Star
2-82	12 36 48	62 13 16	444	392	23.53	-0.63	0.81	1.63	0.11	0.35	P	3	Sa pec, merger? [R]
4-31	12 36 47	62 12 51	434	321	23.53	-1.11	0.76	1.08	0.09	0.31	S	4	Sb pec [b]
4-640	12 36 42	62 11 36	1876	1934	23.54	-0.95	0.93	1.18	0.07	0.38	S	3?	pec [b]
2-234	12 36 48	62 14 13	1783	998	23.54	-0.78	0.48	0.99	0.18	0.28	P	7	tadpole galaxy [aa]
4-682	12 36 38	62 12 33	257	1950	23.55	-0.41	0.93	0.66	0.04	0.35	S	2	S0 [l]
4-375	12 36 45	62 11 44	1895	1366	23.55	-1.11	0.74	0.84	0.25	0.36	P	7	tadpole galaxy
4-253	12 36 47	62 11 52	1856	942	23.56	-1.04	0.45	1.10	0.11	0.46	S	3	Sa pec [b]
4-184	12 36 44	62 12 50	307	738	23.60	-0.19	0.28	0.42	0.28	0.25	P	8	merger [f,vB]
4-235	12 36 46	62 12 06	1487	881	23.60	-0.01	0.64	0.57	0.01	0.42	E	0	E1
3-344	12 36 58	62 12 51	1798	1226	23.60	-0.79	0.95	0.61	0.15	0.34	S	4?	Sb?
4-218	12 36 44	62 12 39	560	864	23.61	-0.94	0.45	1.14	0.08	0.17	P	5	Sc pec [a]
2-513	12 36 54	62 13 48	726	1820	23.63	0.37	0.33	0.36	0.27	0.39	S	8	merger [g,B]
4-7	12 36 47	62 12 54	373	263	23.65	1.63	0.97	0.60	0.17	0.30	P	8	merger
4-387	12 36 41	62 12 38	356	1399	23.67	1.39	0.22	0.35	0.25	0.31	P	0?	E2? t [h,B]
2-33	12 36 44	62 14 10	2031	289	23.67	0.33	0.11	0.28	0.28	0.41	P	8	E + fuzz = merger [B]
4-698	12 36 42	62 11 32	1959	2018	23.68	-1.06	0.77	0.50	0.06	0.29	P	4?	faint edge-on disk
3-315	12 36 56	62 12 53	1557	1084	23.69	-0.47	1.30	1.86	0.11	0.37	E	0	E1 t [h,vR]
3-402	12 36 52	62 12 27	549	1363	23.71	0.07	2.00	2.10	0.06	0.54	E	1	E1 / Sa [vR]
2-93	12 36 46	62 13 57	1579	465	23.75	-0.90	0.75	1.28	0.15	0.39	S	3	Sa pec
2-509	12 36 54	62 13 52	831	1810	23.77	-0.97	0.61	1.13	0.09	0.32	S	3	Sa [R]
3-374	12 36 50	62 12 28	358	1255	23.77	-1.07	0.88	1.11	0.19	0.28	P	7	3 nuclei, merger?
4-241	12 36 44	62 12 43	425	903	23.78	-0.56	0.29	0.35	0.26	0.33	P	7	tadpole gal. or mrg. [B]
3-412	12 36 55	62 12 35	1100	1388	23.79	-0.24	1.29	1.87	0.09	0.53	E	1	E4 / S0 [R]
3-15	12 36 49	62 13 07	571	249	23.80	-1.01	0.32	1.02	0.14	0.37	S	3?	Sa pec?
3-323	12 36 58	62 12 56	1857	1107	23.80	-1.19	0.93	0.74	0.21	0.40	S	4	S [g]
3-56	12 36 54	62 13 14	1457	430	23.80	0.12	0.35	0.38	0.07	0.60	E	-1	E1 (or star)
4-584	12 36 39	62 12 31	396	1768	23.80	-1.03	0.82	1.06	0.03	0.44	S	3	Sa [g]
4-152	12 36 49	62 11 52	1991	639	23.81	-1.28	0.27	0.94	0.11	0.35	P	7	?
3-279	12 36 55	62 12 53	1319	981	23.81	-0.91	0.63	0.87	0.02	0.30	P	4?	clumpy, edge-on, mrg.?
2-242	12 36 48	62 14 18	1930	1043	23.81	0.29	0.40	0.50	0.24	0.36	S	8	merger [B]
4-352	12 36 44	62 11 55	1616	1296	23.82	-1.05	0.43	1.22	0.02	0.32	P	7	?, in group
4-197	12 36 46	62 12 28	903	775	23.88	-0.17	0.45	0.64	0.24	0.35	E	0	E2 t
3-601	12 37 00	62 12 27	1902	1967	23.91	-1.22	0.10	0.71	0.06	0.41	S	3	Sa pec
3-42	12 36 54	62 13 16	1384	354	23.91	-0.94	0.37	0.84	0.09	0.41	S	3	Sa:
4-405	12 36 41	62 12 35	421	1446	23.92	-1.02	0.96	0.94	0.12	0.56	E	0	E1
2-349	12 36 52	62 13 49	950	1374	23.92	-0.87	0.86	0.85	0.04	0.41	E	0	E4
3-531	12 36 54	62 12 18	885	1776	23.92	-0.56	0.29	0.46	0.27	0.31	P	7	Edge-on w/ 3 knots [r,B]
2-228	12 36 48	62 14 15	1848	979	23.94	-1.05	0.42	1.10	0.08	0.57	E	3	Sa pec
4-203	12 36 46	62 12 13	1331	789	23.96	-1.40	0.49	0.73	0.29	0.36	P	7	pec [b]
3-217	12 36 54	62 12 58	1301	815	23.97	-1.40	0.41	1.18	0.25	0.26	P	6	Ir [x,y]
4-103	12 36 47	62 12 15	1347	598	23.98	-1.21	0.80	0.73	0.08	0.47	E	0	E2 [t]
2-131	12 36 45	62 14 12	1950	599	24.01	0.51	0.37	0.38	0.13	0.26	P	8?	? / merger? [B]
2-473	12 36 54	62 13 31	316	1641	24.01	-0.91	0.92	0.87	0.09	0.28	S	4?	1-armed S? prob. merger
2-374	12 36 51	62 14 12	1551	1471	24.01	-0.57	0.15	0.23	0.27	0.30	P	0	E1 + pec, prob. i/a [vB]

Table 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
4-102	12 36 48	62 12 14	1400	520	24.01	-1.13	0.63	0.98	0.11	0.31	P	6:	Ir?
4-259	12 36 46	62 12 03	1512	967	24.01	-1.18	0.80	0.67	0.17	0.44	S	3	Sa t
3-599	12 36 52	62 12 05	449	1956	24.03	-1.11	0.19	0.70	0.05	0.60	E	0	E3
2-555	12 36 54	62 14 08	1237	1952	24.03	-0.05	0.33	0.34	0.16	0.28	P	8	merger ^{vB}
3-631	12 36 54	62 12 04	680	2070	24.03	-0.49	0.61	1.14	0.07	0.40	S	3	Sab pec
3-278	12 36 49	62 12 37	238	962	24.04	0.11	0.44	0.54	0.06	0.38	S	3	Sa pec ^{ag}
2-146	12 36 48	62 13 44	1130	650	24.04	-0.90	0.69	1.15	0.07	0.24	P	8	merger
3-208	12 36 57	62 13 07	1787	770	24.05	0.36	1.76	2.04	0.08	0.45	S	3	Sa ^{vR}
2-514	12 36 53	62 14 11	1361	1817	24.06	1.38	1.24	0.60	0.14	0.44	S	3	Sa pec ^{h}
4-209	12 36 47	62 12 03	1590	818	24.06	-1.26	0.60	1.32	0.09	0.25	P	8	merger $^{R+B}$
3-243	12 36 58	62 13 06	1925	863	24.06	-1.03	0.95	0.82	0.21	0.30	P	7	tadpole galaxy
4-555	12 36 40	62 12 33	357	1729	24.08	-0.92	0.39	0.94	0.17	0.46	E	3	S a t ^{i}
3-406	12 36 59	62 12 50	2074	1382	24.09	-0.76	0.34	0.74	0.13	0.39	S	3	Sa
2-285	12 36 50	62 14 00	1344	1175	24.09	-0.82	0.25	0.71	0.08	0.50	E	3	Sa pec (outer knot)
2-298	12 36 49	62 14 15	1750	1218	24.10	-1.17	0.60	1.19	0.11	0.25	P	6	Ir ^{e,R}
3-268	12 36 50	62 12 43	352	843	24.10	-1.17	0.49	0.88	0.13	0.25	P	7	clumpy, edge-on ^{j}
4-608	12 36 42	62 11 46	1636	1858	24.10	-0.74	0.22	0.39	0.25	0.37	P	8?	pec ^{B}
4-273	12 36 46	62 12 00	1570	1045	24.12	-0.87	1.18	0.82	0.02	0.27	S	4	St
2-275	12 36 50	62 14 02	1400	1165	24.13	0.84	0.44	0.49	0.20	0.42	S	8	merger ^{B}
2-579	12 36 52	62 14 37	2036	2020	24.13	-0.70	0.99	0.58	0.12	0.29	S	8?	2 nuc. in disk, merger?
3-610	12 36 55	62 12 12	1014	1993	24.14	-0.62	0.36	0.73	0.12	0.50	S	0	E1
4-350	12 36 43	62 12 28	700	1275	24.15	-1.12	0.46	1.07	0.08	0.49	S	0	E2 pec, in group ^{b}
2-548	12 36 55	62 13 50	717	1948	24.17	-1.04	0.41	1.12	0.13	0.46	S	0	E1 ^{R}
2-167	12 36 47	62 14 04	1635	749	24.18	-0.54	0.39	0.43	0.03	0.33	P	6	Ir, near star ^{vB}
2-353	12 36 53	62 13 31	436	1378	24.18	1.61	1.04	0.58	0.40	0.34	P	0	E1 + E2, prob. i/a
2-124	12 36 47	62 13 54	1434	587	24.19	-0.91	0.94	0.76	0.11	0.29	S	6?	dIr / merger?
4-628	12 36 40	62 12 05	1072	1887	24.21	-0.80	0.91	1.51	0.05	0.47	E	0	E: 3 ^{g,R}
2-346	12 36 50	62 14 15	1709	1351	24.21	-0.79	0.53	1.07	0.11	0.25	P	6?	Ir?
3-393	12 36 52	62 12 30	706	1340	24.22	0.23	1.45	1.43	-0.01	0.28	S	2:	S0: ^{R}
4-596	12 36 40	62 12 21	643	1841	24.23	-1.00	0.84	0.67	0.26	0.21	P	8	merger
4-242	12 36 44	62 12 44	381	952	24.23	-0.88	1.85	1.89	0.12	0.39	S	0	E0 t ^{vR}
2-65	12 36 45	62 14 06	1883	375	24.23	-0.15	0.37	0.65	0.08	0.41	P	4?	compact, clumpy ^{B}
4-317	12 36 45	62 11 55	1662	1201	24.25	-0.65	0.56	1.02	0.10	0.49	E	0	E0 t ^{g}
3-623	12 36 58	62 12 18	1522	2036	24.25	-0.65	1.13	0.91	0.05	0.35	S	3	Sab
3-409	12 36 50	62 12 22	290	1386	24.28	-1.26	0.79	0.79	0.12	0.46	S	3	Sa
3-578	12 36 58	62 12 25	1650	1915	24.29	—	2.08	1.02	0.19	0.33	P	8	merger
3-264	12 36 49	62 12 49	406	686	24.30	1.27	1.22	0.65	0.13	0.56	E	0	E1 pec
4-92	12 36 49	62 12 08	1603	481	24.30	-0.93	0.67	1.27	0.10	0.37	S	3	Sa pec ^{b,R}
4-494	12 36 41	62 12 30	504	1591	24.31	0.13	0.54	0.73	0.08	0.25	S	4?	S pec or merger
2-40	12 36 46	62 13 29	855	320	24.31	-0.34	1.00	0.66	0.12	0.18	P	6	Ir
2-443	12 36 54	62 13 36	452	1617	24.31	-0.76	0.40	1.16	0.09	0.23	S	7	core + disk ^{b}
4-260	12 36 46	62 12 05	1476	978	24.32	-1.15	0.12	0.54	0.15	0.24	P	7	tidal debris? ^{B}
3-300	12 36 57	62 12 56	1694	1042	24.33	-1.35	0.93	0.80	0.12	0.33	S	3	Sa
4-109	12 36 48	62 12 16	1360	507	24.33	0.48	0.97	1.09	0.36	0.28	P	8	merger
2-104	12 36 48	62 13 25	633	521	24.35	-1.01	0.22	0.72	0.15	0.47	S	3	Sa
2-224	12 36 50	62 13 43	951	984	24.36	-0.73	0.36	0.74	0.12	0.37	S	8	elongated, pec
4-556	12 36 42	62 11 51	1539	1744	24.36	-1.30	0.20	0.72	0.06	0.46	E	0?	E2 pec?
4-570	12 36 41	62 12 01	1231	1792	24.36	-1.23	1.16	0.77	0.04	0.27	S	7	S pec or Ir

Table 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
4-313	12 36 43	62 12 38	459	1149	24.36	0.72	0.36	0.31	0.24	0.35	P	6	merger [B]
4-78	12 36 46	62 12 54	305	461	24.37	-1.13	0.47	1.23	0.04	0.40	S	3	Sa
4-589	12 36 42	62 11 39	1860	1807	24.38	-0.91	0.24	0.65	0.04	0.43	S	3	Sa:
3-617	12 36 53	62 12 03	458	2024	24.39	-0.04	0.33	0.42	0.26	0.34	P	8	merger [f,B]
4-671	12 36 40	62 11 53	1353	2017	24.39	-0.84	0.45	0.53	0.09	0.42	S	3	Sa
2-290	12 36 48	62 14 22	1993	1158	24.40	-0.97	0.22	0.90	0.11	0.47	S	0	E2t + Sa:t
4-454	12 36 44	62 11 45	1835	1450	24.42	-1.23	0.65	0.79	0.14	0.46	S	0	E2 pec [i]
3-399	12 36 58	62 12 46	1747	1358	24.42	-1.04	0.73	1.14	0.03	0.43	S	3	Sa
2-401	12 36 50	62 14 28	1998	1514	24.43	-0.91	0.64	0.86	0.06	0.43	S	0	E4
4-274	12 36 43	62 12 41	437	1029	24.44	0.11	3.78	1.35	0.15	0.49	S	1	E0 / Sa t
4-562	12 36 41	62 12 11	969	1767	24.45	-0.82	1.08	0.80	0.01	0.36	S	0	E0
4-63	12 36 49	62 12 15	1438	406	24.45	-1.21	0.41	1.03	0.30	0.26	P	8	merger
3-621	12 36 55	62 12 09	912	2036	24.46	-1.49	0.35	1.24	0.25	0.26	P	7	tadpole galaxy
2-531	12 36 55	62 13 37	392	1873	24.47	-1.18	0.47	0.98	0.05	0.34	S	3	Sa pec
3-572	12 36 55	62 12 16	1065	1899	24.47	-0.81	0.22	0.62	0.10	0.27	S	4	S pec [B]
2-571	12 36 54	62 14 08	1213	1997	24.48	-0.54	0.26	0.50	0.15	0.46	S	3	Sa: [B]
4-576	12 36 39	62 12 37	227	1787	24.48	-0.31	0.41	1.28	0.09	0.30	S	8	merger
2-25	12 36 45	62 13 48	1408	263	24.50	-0.10	0.60	0.42	0.14	0.39	P	8	Ir / merger
3-379	12 36 51	62 12 28	434	1287	24.50	-0.15	0.32	0.27	0.21	0.27	P	8:	tadpole gal. or merger [B]
2-12	12 36 43	62 14 09	2044	196	24.51	0.87	0.45	0.65	0.20	0.25	P	8	Ir / merger
4-372	12 36 42	62 12 32	549	1349	24.54	0.05	0.39	0.50	0.11	0.52	E	0	E2
2-487	12 36 55	62 13 36	430	1719	24.55	-0.83	0.22	0.63	0.06	0.22	S	4?	pec / merger? [B]
2-169	12 36 46	62 14 18	2056	746	24.55	-1.23	0.62	0.96	0.03	0.24	S	?	core + envelope [a]
2-302	12 36 51	62 13 50	1038	1220	24.56	2.15	0.73	0.52	0.20	0.40	S	8	Pec + St (merger) [ab]
3-468	12 36 51	62 12 18	380	1537	24.56	0.81	0.53	0.74	0.21	0.38	S	8	binary merger
4-667	12 36 42	62 11 28	2074	2017	24.56	-1.10	0.84	0.83	0.08	0.44	S	0	E1
2-193	12 36 50	62 13 31	665	880	24.57	0.22	0.35	0.46	0.10	0.45	P	8	E + ?, merger [B+vB]
3-183	12 36 54	62 13 01	1235	710	24.58	-0.69	0.50	1.01	0.07	0.25	S	7	pec
2-356	12 36 53	62 13 27	319	1396	24.59	0.59	0.47	0.47	0.14	0.25	P	6	Ir / merger [h,B]
3-462	12 36 53	62 12 24	700	1526	24.59	-1.11	0.58	0.97	0.04	0.52	E	0	E2 [p]
3-526	12 36 57	62 12 28	1440	1732	24.60	-0.63	0.41	0.85	0.02	0.34	P	3	Sa:
4-365	12 36 44	62 11 58	1527	1319	24.60	-1.25	0.62	0.71	0.13	0.52	E	-1	E0 or star
3-511	12 36 58	62 12 31	1580	1709	24.60	-0.83	0.64	0.94	0.14	0.33	S	4	S
2-221	12 36 49	62 13 53	1197	1059	24.61	0.19	0.27	0.32	0.18	0.42	S	0	E3 pec, near merger [c,B]
4-355	12 36 43	62 12 16	1029	1306	24.61	-1.49	0.76	0.86	0.08	0.21	S	6	Ir
4-227	12 36 48	62 11 47	2028	853	24.61	—	0.87	0.53	0.15	0.38	P	4	S? t
4-509	12 36 44	62 11 35	2073	1548	24.65	—	2.08	1.99	0.08	0.41	S	0	E1 [R i]
3-23	12 36 56	62 13 24	1788	290	24.65	-1.10	1.57	2.01	0.02	0.45	E	3	Sa [vR]
4-179	12 36 46	62 12 33	790	716	24.65	-1.23	0.55	1.19	0.06	0.33	S	1	E6 / Sa
2-22	12 36 45	62 13 45	1336	254	24.65	-1.16	0.71	0.43	0.05	0.36	S	4	E? / Sa pec [b]
2-351	12 36 52	62 13 41	706	1367	24.65	1.95	1.04	0.54	0.21	0.45	S	-1	E0 or Star
4-535	12 36 43	62 11 36	1998	1680	24.66	2.41	2.33	2.02	0.03	0.39	E	-1	E0 or Star [vR]
3-332	12 36 51	62 12 34	493	1136	24.67	-0.42	0.31	0.36	0.10	0.37	S	3	Sa pec [B]
3-57	12 36 54	62 13 13	1389	421	24.69	-1.11	0.05	0.34	0.19	0.35	P	8?	pec or merger [B]
3-425	12 36 51	62 12 22	386	1446	24.69	-1.17	0.36	0.87	0.08	0.44	S	1	E1 / S0 [n]
4-33	12 36 49	62 12 20	1342	300	24.71	0.77	0.46	0.40	0.07	0.39	P	7	? [h]
2-522	12 36 52	62 14 23	1714	1832	24.72	-0.54	0.17	0.33	0.25	0.38	S	7	Star + backround gal.? [B]
3-43	12 36 55	62 13 18	1544	360	24.74	-0.60	1.90	1.73	0.08	0.36	S	-1	E0 (or Star) [R]

Table 1. (continued)

ID	RA	Dec	X	Y	I	$U-B$	$B-V$	$V-I$	A	C	RSE	vdB	Description
4-408	12 36 41	62 12 41	257	1420	24.75	-1.23	1.02	0.98	0.01	0.28	S	3?	Sab pec?
4-165	12 36 46	62 12 26	1007	681	24.75	—	0.48	0.26	0.30	0.37	P	0	E0 + E1 t [B]
4-59	12 36 49	62 12 13	1499	381	24.75	0.01	0.37	0.35	0.06	0.39	P	4:	pec [B]
3-298	12 36 56	62 12 56	1640	1011	24.76	-0.96	0.44	1.01	0.15	0.34	S	7	? [l]
3-616	12 36 58	62 12 18	1450	2022	24.76	1.09	0.41	0.51	0.03	0.42	S	3	Sa pec
3-491	12 36 59	62 12 39	1845	1606	24.77	0.71	1.36	1.36	0.01	0.34	E	-1	E0 or Star [R]
4-90	12 36 47	62 12 36	796	464	24.78	0.35	1.30	0.90	0.04	0.32	E	3	Sa
4-308	12 36 45	62 12 06	1359	1170	24.78	-0.20	0.26	0.36	0.17	0.21	P	8	merger [vB]
4-368	12 36 41	62 12 43	256	1330	24.79	2.05	0.81	0.44	0.01	0.19	S	6	d Ir
2-233	12 36 48	62 14 08	1662	985	24.80	-1.28	1.04	1.53	0.02	0.33	S	3	Sa pec [vR]
2-459	12 36 54	62 13 43	626	1689	24.80	0.66	0.31	0.39	0.24	0.28	P	8	triple merger [af]
4-188	12 36 47	62 12 11	1388	738	24.81	-0.94	0.22	0.49	0.13	0.28	P	5	pec or merger [vB]
4-318	12 36 45	62 11 46	1903	1209	24.82	-0.86	0.25	0.99	0.07	0.39	P	7	?, near bright S
2-467	12 36 55	62 13 32	308	1699	24.83	-0.77	0.30	0.96	0.07	0.32	S	2	E3 / Sa [g]
4-392	12 36 44	62 11 51	1679	1397	24.84	-2.15	3.14	1.77	0.15	0.29	P	4	S: t [vR]
2-367	12 36 51	62 14 09	1469	1444	24.87	-0.69	0.67	1.10	0.03	0.35	S	0?	E1 pec? (tidal tail?)
2-569	12 36 56	62 13 41	449	1999	24.88	1.13	0.41	0.80	0.17	0.24	P	8:	
2-67	12 36 47	62 13 35	969	393	24.88	-1.06	0.37	1.05	0.03	0.27	S	4?	Sb:
4-571	12 36 42	62 11 47	1634	1781	24.89	-1.47	0.33	1.02	0.10	0.36	S	4?	S?
2-526	12 36 54	62 13 49	744	1845	24.91	1.30	0.62	0.48	0.28	0.29	P	7	tadpole galaxy [h,B]
3-494	12 36 56	62 12 30	1355	1638	24.92	-0.67	0.26	0.42	0.09	0.20	P	7	Ir or merger [B]
4-388	12 36 41	62 12 38	342	1427	24.92	0.73	2.77	1.29	0.03	0.40	S	0	E1 [u]
3-448	12 36 52	62 12 26	597	1429	24.92	-0.35	0.23	0.21	0.28	0.34	P	7	tadpole galaxy [B]
3-192	12 36 53	62 12 57	1018	729	24.93	-1.20	0.80	0.73	0.00	0.34	S	4	S? [h]
3-465	12 36 53	62 12 25	774	1537	24.94	-0.92	0.13	0.26	0.31	0.28	P	8	binary merger [B]
2-24	12 36 46	62 13 36	1074	258	24.95	-1.20	0.58	0.83	0.08	0.33	E	0	E2 [d]
2-463	12 36 52	62 14 15	1541	1693	24.95	-1.30	0.32	1.02	0.17	0.24	P	7	compact / Ir?
3-26	12 36 48	62 13 02	367	295	24.96	-0.85	1.23	0.77	0.03	0.39	E	-1	E0 or Star
2-83	12 36 48	62 13 17	438	436	24.96	-0.38	1.08	0.82	0.03	0.32	S	4?	S pec?, merger
3-267	12 36 50	62 12 44	374	817	24.98	0.24	0.37	0.48	0.02	0.33	P	3:	? [i,B]
2-491	12 36 52	62 14 21	1694	1734	24.99	-0.62	0.23	0.40	0.05	0.38	S	0	E3 pec [b,B]
4-655	12 36 39	62 12 14	786	1992	25.00	1.34	1.04	0.43	0.25	0.47	S	7	pec

[a] possibly a very distant Sc viewed in UV.
[b] asymmetrical.
[c] companion to 2-220.
[d] has faint companions.
[e] companion to 2-299.
[f] good example of merger.
[g] has companions.
[h] has companion.
[i] has bright companions
[j] companion to 3-267
[k] has bright bar-like core
[l] has bright companion
[m] part of spiral (?) arm of 3-296
[n] companion to 3-426
[o] star off center
[p] companion to 3-426
[q] companion to 3-517
[r] chain galaxy?
[s] interacting with 3-606
[t] companion to 4-105
[u] companion to 4-387
[v] gravitational lens?
[w] companion to 4-655

[aa] "tadpole" with R head and B tail
[ab] Pec component vB
[ac] blue compact companion
[ad] has one blue arm
[ae] one component R
[af] triple merger, all components B
[ag] or tadpole galaxy
[af] E1 galaxy is R, companion is B

Table 2. Number of different DDO classifications in SAC, MDS, and HDF

Type	HDF[a]	MDS	SAC
E	68 (33.5)	68 (37.5)	[b]
E/S0	3 (1)	8 (7.5)	208
S0	8 (6)	21.5 (15.5)	[b]
S0/Sa	1 (1)	0 (0)	0
E/Sa	6 (2)	4 (0)	12
Sa	44.5 (20.5)	27 (17)	64.5
Sab	5 (2)	17 (7)	2
Sb	7 (6)	54 (16)	252
Sbc	0 (0)	16 (9)	3
Sc	3 (2)	75 (29)	214.5
Sc/Ir	0 (0)	5 (2)	2
Ir	13 (3.5)	45 (14.5)	19
S	18.5 (18.5)	81.5 (33)	93.5
Unclassified	113 (44)	86 (38)	65.5
Total	290 (140)	508 (226)	936

[a]If two images appeared equidistant from the field center then the classification of the first object was used.
[b]The SAC makes no distinction between E, E/S0, and S0.

TABLE 3. Binned DDO morphological types

Type	HDF	MDS	SAC
E + S0	79 (40.5)	97.5 (60.5)	208
S0/Sa + E/Sa	7 (3)	4 (0)	12
Sa + Sab	49.5 (22.5)	44 (24)	66.5
Sb + Sbc	7 (6)	70 (25)	255
Sc + Sc/Ir	3 (2)	80 (31)	216.5
Ir	13 (3.5)	45 (14.5)	19
S	18.5 (18.5)	81.5 (33)	93.5
unclassified	113 (44)	86 (38)	65.5

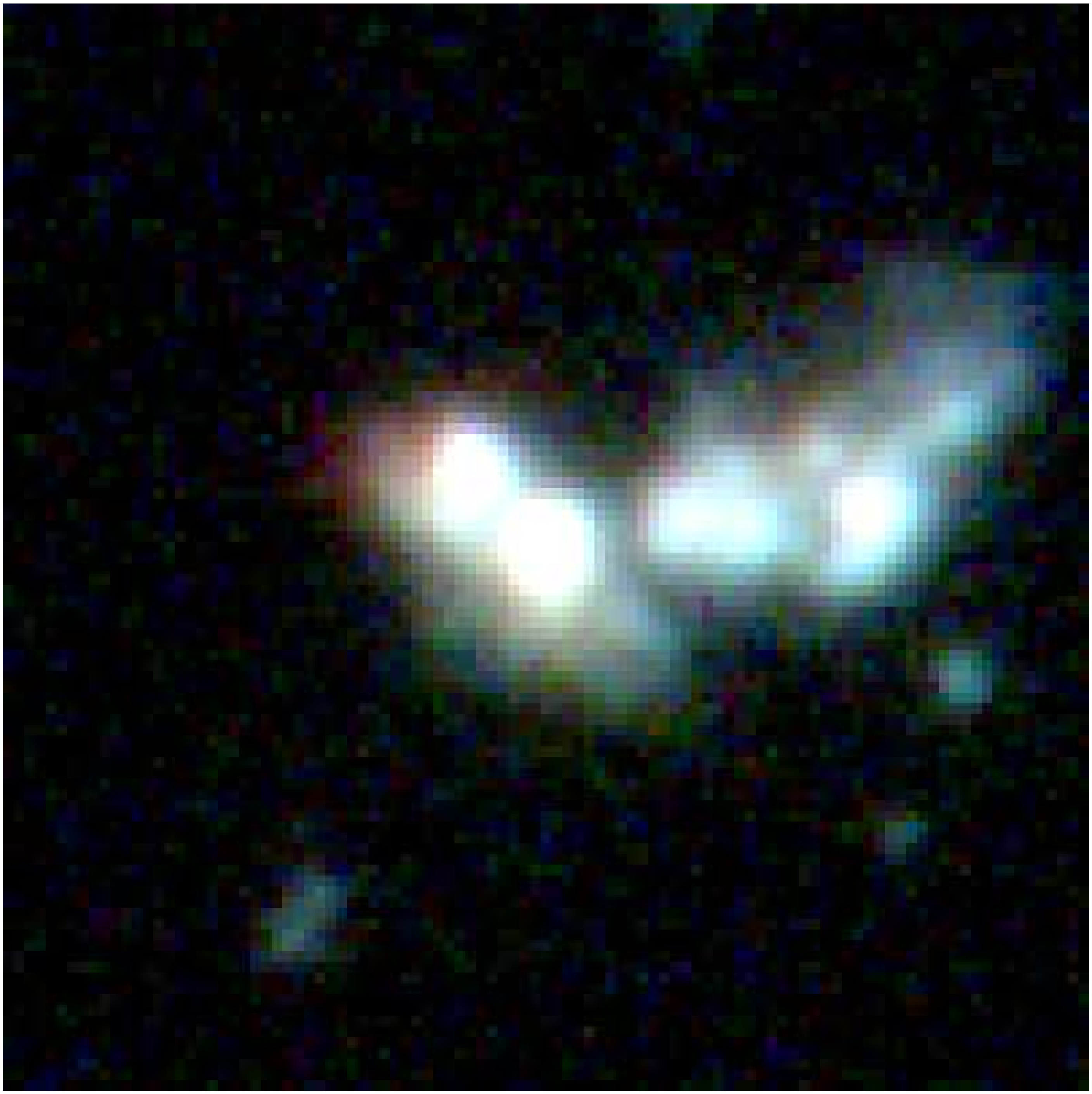

TABLE 4. Percentage of galaxies in various DDO classification bins

Type	HDF	MDS	SAC
E + S0	27% (29%)	19% (27%)	22%
S0/Sa + E/Sa	2 (2)	1 (0)	1
Sa + Sab	17 (16)	9 (11)	7
Sb + Sbc	2 (4)	14 (11)	27
Sc + Sc/Ir	1 (1)	16 (14)	23
Ir	4 (2)	9 (6)	2
S	6 (13)	16 (15)	10
unclassified	39 (31)	17 (17)	7

Table 5. Coarse binning of galaxy classifications

Type	HDF[a]	MDS	SAC
E/S0	30% (31%)	20 (27%)	24%
S/Irr	31% (38%)	63 (56%)	69%
not classified	39% (31%)	17 (17%)	7

Table 6. Frequency of tidal interactions and mergers

Survey	t? (w=1)	t (w=2)	m? (w=3)	m (w=4)
HDF	2	20	27	39
MDS	19	37	8	4
SAC	22	65	0	3[a]

[a]Objects listed as “colliding” in SAC.

A MORPHOLOGICAL CATALOG OF GALAXIES IN THE *HUBBLE DEEP FIELD*

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ABSTRACT

We present a catalog of morphological and color data for galaxies with $21 < I < 25$ mag in the *Hubble Deep Field* (Williams et al. 1996). Galaxies have been inspected and (when possible) independently visually classified on the MDS and DDO systems. Measurements of central concentration and asymmetry are also included in the catalog. The fraction of interacting and merging objects is seen to be significantly higher in the *Hubble Deep Field* than it is among nearby galaxies. Barred spirals are essentially absent from the deep sample. The fraction of early-type galaxies in the Hubble Deep Field is similar to the fraction of early-types in the Shapley-Ames Catalog, but the fraction of galaxies resembling archetypal grand-design late-type spiral galaxies is dramatically lower in the distant HDF sample.

1. INTRODUCTION

Recently published results from the *Hubble Deep Field* (HDF) survey (Abraham et al. 1996a), in conjunction with earlier data from the *Medium Deep Survey* (MDS) (Griffiths et al. 1994, Glazebrook et al. 1995, Driver et al. 1995, Abraham et al. 1996b), and samples of local galaxies such as that given in the Shapley-Ames Catalog (SAC) (Shapley & Ames 1932), allow one to study the morphological evolution of galaxy populations as a function of look-back time. On the basis of bulk measurements of central concentration, C, and asymmetry, A, for galaxies in the HDF and MDS (calibrated using an artificially redshifted sample of local galaxies with Hubble types earlier than Scd), Abraham et al. (1996a) conclude that by $I = 25$ mag the fraction of "peculiar" objects has risen to at least 30% of the galaxy population. The exact nature of these peculiar systems remains enigmatic: they may be luminous very-late-type spirals or irregulars seen in the rest-frame ultraviolet, mergers, or else systems with no local counterpart. The UV-optical colors of these peculiar systems suggests that a substantial fraction of faint peculiars might be at very high redshifts ($z > 3$).

Parameters such as C and A have the important benefit of being objective *measurements*, but these simple parameters describe only a subset of the morphological information contained in the HDF images, and are not designed to detect relatively subtle features (eg. bars and tidal tails), which at present still require subjective visual inspection (and human expertise) in order to be detected. In the present paper we present a morphological catalog of $21 < I < 25$ mag galaxies in the *Hubble Deep Field*, including both visual classifications on the MDS (Glazebrook et al. 1995; Abraham et al. 1996b) and DDO (van den Bergh 1960a, b) systems, as well as measurements of the morphological parameters C and A studied in Abraham et al. (1996a). The plan of this paper follows. In §2 we describe the format of the HDF catalog, and outline the steps that have been taken in order to allow meaningful comparisons to be made between the visual classifications of objects in the HDF and visual classifications in the MDS and SAC. In §3 we show specific examples of different classes of peculiar objects, in order to clarify the terminology used in the catalog. In Section 4 we discuss the relative fractions of various morphological types in the HDF, MDS, and SAC catalogs. A number of model-independent statements can be made directly from this comparison, which both support and expand upon the conclusions given in Abraham et al. (1996a). A major new conclusion is that both barred and "grand-design" spiral structure is rare in HDF galaxies. In Section 5 we attempt to understand more about the nature of peculiar systems in the *Hubble Deep Field*, by determining the fraction of peculiar galaxies that show evidence for tidal interactions. New evidence is presented suggesting that a substantial fraction of the peculiar systems in the HDF and MDS are tidally distorted. §6 summarizes our

conclusions.

2. THE HDF CATALOG

The HDF data catalog is presented in Table 1, which has a format similar to that of the MDS data recently published by Abraham et al. (1996b). The table lists (1) the galaxy ID number, (2) the J2000 coordinates, (3) the pixel coordinates on the "drizzled" HDF frames released by STScI[1], (4) the I magnitude, (5) the $U-B$ color index, (6) the $B-V$ color index, (7) the $V-I$ color index, (8) the asymmetry and (9) central concentration measures from Abraham et al. (1996a), (10) the visual classification by RSE into three large bins (E=elliptical, S=spiral, P=irregular/peculiar/merger), (11) the visual classification by vdB on the numerical "MDS system" used by RSE to classify the data in Glazebrook et al. (1995), and described in detail in Abraham et al. (1996b)[2], and (12) the galaxy classification by vdB on the DDO system. Remarks on the DDO classifications are shown as footnotes, and include, for example, references to a few HDF galaxies that have a peculiar morphology that simulations suggest might possibly be the result of band-shifting effects which will be discussed below. The remarks also draw attention to a few objects classified as E0 which might, in fact, be Galactic foreground stars. All uncertain classifications are followed by a colon. The catalog was constructed using the prescription given in Abraham et al. (1996a). (Note particularly that the colors presented have have been obtained using the instrumental calibrations of Holtzman et al. 1995). The 42 high-z candidates with red UV-optical colors ($U - B > -0.2$) and blue optical-near IR colors ($V - I < 0.6$), indicating the possible presence of the Lyman discontinuity in the U-band spectral energy distribution (Steidel et al. 1996), are indicated in boldface in the first column. A montage showing all these galaxies is shown in Figure 1. The morphological characteristics of these objects are described in Section 6 below.

The large redshift range of the HDF and MDS datasets is an important consideration when making comparsions between these surveys and local galaxy catalogs. Bandshifting effects result in the MDS and HDF samples having very inhomogeneous rest-frame color selection criteria. For objects with $z < 1$ the effects of bandshifting are (to first order) compensated for by the fact that most nearby galaxy catalogs

[1]Note that the first digit in the ID numbers corresponds to the WF/PC2 chip on which the object lies.

[2] The numerical designations are as follows: -1 = compact, 0 = E, 1 = E/S0, 2 = S0, 3 = Sab, 4 = S, 5 = Scdm, 6 = Ir, 7 = peculiar, 8 = merger and 9 = defect.

(such as the SAC) were constructed in the B-band, whereas the MDS and HDF images were obtained in I-band (F814W filter). However at higher redshifts galaxies are being observed in the rest-frame ultraviolet, where their morphological properties are less well-understood than in B-band. For fainter galaxies, bandshifting effects have been estimated by comparing the appearance of galaxies in the HDF survey to the results from simulations[3] in which local galaxies (with Hubble types between E and Sc) were artificially redshifted to $z = 2$, and to preliminary data from an ongoing U-band survey of local galaxies (being prepared in Cambridge). The main conclusion from these simulations is that faint "chain-like" linear galaxies need to be interpreted with some caution, since the appearance of these objects is quite similar to the expected appearance of distant late-type spirals seen edge-on in the rest-frame ultraviolet.

A major objective of the present catalog is to provide precise classifications for objects using the morphological bins of the DDO system (in which the great majority of local objects find a home). Objects (such as probable mergers) that do not naturally fit into the DDO scheme (or which cannot be "shoe-horned" into the system by assuming a reasonable contribution from bandshifting effects) have been flagged as peculiar by being designated 7 or 8 in the numerical MDS system. Since these objects cannot be classified on the DDO system they have instead been given a general qualitative remark (eg. "merger", for probable mergers, or "tadpole galaxy" for head-tail systems) in the last column of Table 1. We emphasize that classifying peculiar objects into broad categories (such as mergers) is particularly subjective (see §5 below), but since the merger fraction is of great interest it seems useful to flag the subset of peculiar galaxies that are at the best candidates for being interacting systems.

It is important to emphasize that many of the objects that cannot be classified into the DDO system exhibit "generic" features similar to those seen in local spiral galaxies (eg. an amorphous disk with a bulge), but the poorly defined spiral structure in these objects does *not* correspond closely to the images of local archetypal spirals defining the Hubble sequence within the DDO system, or to the artificially redshifted spirals in our (incomplete) local galaxy sample. In addition to peculiar objects that resemble distant spiral galaxies in a general sense, large numbers of peculiar systems are seen that do not resemble spirals at all. For example, inspection of the images of HDF images reveals the existence of a class of head-tail galaxies resembling tadpoles (see Fig. 2), which comprise about 3% of the galaxies in the HDF. The only local

[3]As described in Abraham et al. (1996b), the local galaxies used in these simulations are K-corrected on a pixel-by-pixel basis, with the spectral energy distribution appropriate to each pixel estimated from optical colors.

analog of such an object that we are aware of is NGC3991, which is illustrated in plate I of Morgan (1958).

"True-color" images of the HDF galaxies brighter than $I = 25$ mag were produced by stacking the V, R, and I band frames into blue, green, and red channels. Qualitative remarks on the colors of individual galaxies are also shown in the body of Table 1 and in the remarks to this table. In these remarks we have used the following abbreviations: vB=very blue, B=blue, R=red and vR=very red. In general the "true-color" images revealed that (a) The majority of "tadpole" galaxies were quite blue in color. (b) A few images that appeared chaotic or irregular on the I-band image contained a single red knot, which can presumably be identified with their stellar nuclear bulge, in the pseudo-color image. In some other images bluish clumps cluster around a relatively red central region. Presumably these are objects that are in the early stage of evolving into conventional spiral galaxies. (c) Although most E galaxies appeared to be red, a few of them had quite blue colors. Presumably these are (proto?) ellipticals that have only recently formed stars, or possibly misclassified stars.

3. REPRESENTATIVE IMAGES OF *HUBBLE DEEP FIELD* GALAXIES

The following are examples of some of the unique types of objects represented in the HDF catalog, intended to illustrate the general criteria used in the catalog when classifying galaxies as "peculiar".

HDF 2-234 (Fig. 2). $I = 23.54$ mag, $B - V = 0.48$. This is a good example of a "tadpole" (head-tail) galaxy. It is, however, slightly atypical because the head is relatively red, whereas the tail is blue. In most tadpole galaxies both the head and tail are blue.

HDF 2-86 (Fig. 3). $I = 22.27$ mag, $B - V = 0.50$. This image may show an early phase in the formation of a spiral galaxy. The central knot, has a slightly orange tinge in the Figure, indicating that at least a few evolved stars are present, is embedded in a chaotic structure of blue knots in which active star formation presently seems to be taking place.

HDF 2-403 (Fig. 4). $I = 21.57$ mag, $B - V = 0.35$. This image shows a multiple merger of at least a half dozen blue knots. Most of these knots are seen to have a high surface brightness.

HDF 3-312 (Fig. 5). $I = 22.69$ mag, $B - V = 0.64$. This object may represent a spiral galaxy at an early stage in its evolution. It contains a relatively red nucleus, which is located asymmetrically within a structure containing many blue knots. The observed colors suggest that the light of the bulge is dominated by evolved stars, whereas the knots surrounding it contain young blue stars. It is interesting to note that

objects such HDF 3-312, with relatively red bulges surrounded by rather chaotic structure including a number of blue knots, seem to be excellent proto-spiral candidates, and supply rather direct evidence in support of the widely-held view that bulges form before disks.

HDF 3-531 (Fig. 6). $I = 23.92$ mag, $B - V = 0.29$. This string of blue knots may be related to the "chain galaxies" recently reported by Cowie et al. (1995) and, perhaps, more distantly, to the "tadpole galaxies" discussed above.

HDF 4-105 (Fig. 7). $I = 22.22$ mag, $B - V = 0.74$. This object, which was classified S(B)ct on the DDO system, is the *only* barred spiral in the entire HDF sample. An alternative interpretation of its morphology is that this object is a peculiar spiral that is being tidally deformed by an elliptical companion. The fact that at only one barred spiral is observed in the HDF shows that *the frequency of barred objects is an order of magnitude lower than it is among nearby galaxies*. This point is discussed in more detail below.

4. FREQUENCY OF MORPHOLOGICAL TYPES

Because the comparison between the morphologically segregated number counts and no-evolution models presented in Abraham et al. (1996a) is dependent upon assumptions made with regard to the normalization and faint-end slope of the local luminosity function, it is interesting to consider what model-independent statements can be made directly from the observed fractions of various morphological types given in Table 1. The numbers of galaxies of various DDO classification types in the HDF, MDS and SAC[4] are listed in Table 2. These data represent the finest morphological binning that can be made, on a strictly comparable basis, for all three surveys. In Table 3 the morphological data have been grouped

[4]The only differences between the DDO morphological classification systems used for classifying galaxies in the HST data, and the system used to classify galaxies in the SAC, are as follows: (1) E and S0 galaxies could not be distinguished on the prints of the Palomar Observatory Sky Survey (POSS) used for the SAC, and therefore both classes of object were denoted by E in van den Bergh (1960c). (2) "probable collisions" in the SAC are referred to as "probable mergers" in the classification of MDS and HDF galaxies. Both the classifications of MDS and HDF galaxies were made by interactive inspection of images that displayed intensity on a logarithmic scale. This made these images quite comparable in texture and contrast to SAC galaxies classified on the POSS prints. The present data are therefore well-suited to an intercomparison between the galaxy populations in the HDF, MDS and SAC.

together into somewhat wider morphological bins. The corresponding percentages of galaxies in each classification bin are given in Table 4. Finally, Table 5 lists the coarsest possible binning within the DDO system in which galaxies have been designated either E/S0 (E, E/S0, S0, S0/Sa, E/Sa), or Spiral/Irr (Sa, Sab, Sb, Sc, Sbc, Sc/Ir, Ir, S), or "not classified". In Tables 2–5 below (and in the next paragraph) the numbers given in parentheses correspond to values for $I < 24$ mag in the HDF, and $I < 21$ mag in the MDS. Because the morphological classification of galaxies in both the HDF and MDS samples was extended to rather low signal-to-noise limits, the numbers in parentheses are our most robust (and conservative) estimates.

Inspection of the data in Tables 2–5 shows that the fraction of unclassified galaxies in the DDO system rises from 7% in the SAC to 39% (31%) in the distant HDF sample. In other words, of order half the galaxies in the HDF cannot be directly incorporated into the Hubble scheme (cf. Abraham et al. 1996a). While the interpretation of this result is somewhat sensitive to the (currently unknown) redshift distribution of galaxies in the HDF and MDS, the fraction of peculiar systems in the MDS and HDF is nearly an order of magnitude greater than the fraction of very-late-type spirals predicted from no-evolution models (Glazebrook et al. 1995, Abraham et al. 1996a, b). It thus appears that the majority of MDS and HST "peculiars" do not appear distorted as the result of bandshifting effects. *An even more dramatic evolution occurs for barred spirals* (van den Bergh et al. 1996) which account for 22% of the nearby SAC sample, 4% of the MDS galaxies and only 0.3% of the distant objects in the HDF. On the other hand, the fraction of E/S0 galaxies remains approximately constant from nearby Shapley-Ames galaxies at $24 \pm 2\%$, to distant HDF galaxies at $30 \pm 3\%$ ($31 \pm 5\%$). It is emphasized that while redder galactic features (eg. bars) may appear dimmer at high redshifts due to bandshifting effects, artificial redshifting of local barred spiral galaxies (Figure 8) suggests that most bars should be detectable out to redshifts beyond $z = 1.5$. [5]

5. INTERACTING AND MERGING SYSTEMS

The distinction between tidally distorted/merging systems and other categories of peculiar objects is difficult to make without dynamical information. Because this distinction is so important, however, and because some characteristics of tidal interaction are rather evident from visual inspection alone (eg. tails,

[5]Nuclear bulges are evident in many spiral or spiral-like systems in the HDF. If bars and bulges are of similar color, as is the case locally, then prominent bars and bulges should be detectable to similar redshifts

multiple nuclei), an attempt has been made to place galaxies in the HDF, MDS, and SAC into in a sequence ranging from objects showing no tidal distortion ($w = 0$), through objects showing possible tidal effects ($w = 1$), via galaxies exhibiting probable tidal distortions ($w = 2$), to possible mergers ($w = 3$) and finally to objects that are almost certainly merging ($w = 4$). Such information on galaxies in the HDF, MDS and SAC samples is collected in Table 6. These data allow one to define a normalized interaction index:

$$I_i = \sum_j \frac{w_{ij}}{N_i} \tag{1}$$

in which w_{ij} is the w value for the jth galaxy in the ith sample, and N_i is the number of galaxies in that sample. From the data listed in Table 1 it is found that $I = 0.96$ for the distant HDF sample, $I = 0.26$ for the MDS galaxies, and $I = 0.18$ for nearby objects in the SAC catalogue. These results show that the normalized interaction index increases precipitously with increasing magnitude (and, by implication, look-back time).

6. DISCUSSION

Intercomparison of galaxies in the SAC, MDS and HDF catalogs allows one to probe the observed changes in the morphology of galaxies with increasing look-back time. The present results indicate that the observed fraction of Es and S0s remains constant at 1/4 or 1/5 of all galaxies in all three surveys. However the observed fraction of canonical grand design spiral galaxies of types Sb + Sbc + Sc is an order of magnitude smaller in the HDF relative to the RSA. In the HDF only 3% of all galaxies belong to types Sb-Sc, compared to 29% in the MDS and 50% in the SAC. The data in Table 5 show that the fraction of galaxies that do not find a home in the DDO/Hubble classification scheme rises steeply from 7% in the SAC to 39% in the HDF. This observation appears consistent with scenarios (Toomre 1977) in which there was "a great deal of merging of sizable bits and pieces (including quite a few lesser galaxies) early in the career of every major galaxy".

The majority (26/42) of high-redshift candidates selected on the basis of red UV-optical colors ($U - B > -0.2$) and blue optical-near IR colors ($V - I < 0.6$) shown in Figure 1 are classified as mergers, peculiars, or irregulars on the DDO system (8, 7, or 6 on the MDS system). With effective exposure times an order of magnitude shorter than those of the HDF, Giavalisco et al. (1996) found that candidate high-z galaxies (selected on the basis of UV-optical colors) do *not* generally appear to extended and distorted, as

reported here. Instead Giavalisco et al. find that high-z candidates appeared to exhibit a fairly narrow range of compact and generally spherically symmetric morphologies. They also note that in several cases these compact objects are surrounded by low-surface-brightness asymmetric nebulosities. A number of galaxies in the HDF fit this description, but such objects appear to constitute a relatively small fraction ($< 30\%$) of high-z candidate galaxies in the Hubble Deep Field. The apparent discrepancy between these results may simply be due to the much greater depth of the HDF images, which allows extended, irregular structures to be detected, or due to the relatively small number statistics involved. (There are 19 high-z candidates in Giavalisco et al., but only 11 of these are brighter than $m_{AB} = 25$ mag. In the present HDF catalog 42 high-z candidates are at $I < 25$ mag).

The relatively constant fraction of ellipticals in the RSA, MDS, and HDF catalogs must be accounted for if merger models for the origin of ellipticals are to prove succesful. The importance of bandshifting effects prevents us from being able to estimate the volume density of ellipticals directly from the observational data, without reference to detailed modelling of the number counts. A determination of the redshift distribution of the ellipticals in the HDF catalog would likely prove extremely interesting: if most early-type galaxies existed before spiral galaxies were assembled (hinted at by the large fraction of ellipticals at faint magnitudes), then ellipticals are unlikely to have formed from merging spirals. A similar conclusion has previously been reached by van den Bergh (1982, 1990) from the observation that the specific frequency of globular clusters in ellipticals is higher than it is in spirals. Recently Geisler, Lee, & Kim (1996) have shown that the peak of the metallicity distribution function of metal-poor globular clusters is located at a systematially higher value of [Fe/H] in ellipticals than it is in spirals. This observation appears difficult to reconcile with a model in which ellipticals are formed from merging spirals, since such a scenario one would have expected the distribution functions for metal-poor globular clusters to peak at the same value in elliptical and spiral galaxies.

The absence of barred spirals may exclude scenarios (eg. Pfenniger 1993) in which galactic bulges are formed from bars. Because of the importance of our conclusion that barred spirals are very rare among the galaxies in the HDF, we have re-examined the images of the 65 galaxies with $I < 23.0$ mag, looking for even the *slightest evidence* for a nuclear bar. Since these objects also tend to be among the largest galaxies in the HDF it is possible to observe their structure in more detail than is the case for the smaller and fainter images. This detailed re-inspection supports our conclusion that barred spirals are very rare in the HDF. The following are comments on the 6 (9%) of these bright galaxies with $I < 23.0$ mag of that exhibit an extended nuclear structure that *might* be interpreted as being related to a nuclear bar:

HDF 3-296: While this object is classified as a 'merger?', it could also be reinterpreted as a dwarf galaxy of type S(B) IV.

HDF 4-105: Classified as 'S(B)c t', this object might also be an Sc that is presently being distorted by a nearly compact companion.

HDF 2-553: The nuclear region of this object is slightly elongated. This galaxy might also be interpreted as being of type S(B)/Ir(B).

HDF 2-352: This one-arm spiral has an elongated nuclear bulge.

HDF 2-121: Classified as 'Sbt?', this galaxy has an elongated nuclear region.

HDF 2-416: This object is a peculiar one-arm spiral with slightly elongated bulge.

It is therefore concluded that the observed absence of barred spirals in the *Hubble Deep Field* is unlikely to be the result of low signal-to-noise in the data. The absence of nuclear bars in faint galaxies may prove to be an important clue to the origin of galactic structure, although a detailed interpretation of this effect will depend, like so many other effects, upon the redshift distribution of galaxies in the HDF.

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REFERENCES

??braham, R. G., Tanvir, N. R., Santiago, B. X., Ellis, R. S., Glazebrook, K. & van den Bergh, S. 1996a, MNRAS, 279, L47

??braham, R. G., van den Bergh, S., Ellis, R., Glazebrook, K., Santiago, B., Griffiths, R.E. & Surma, P. 1996b, ApJ, in press

??braham, R. G., Vales, F., Yee, H. K. C. & van den Bergh, S. 1994, ApJ, 432, 75

??owie, L. L., Hu, E. M. & Songaila, A. J. 1995, AJ, 1576

??river, S. P., Windhorst, R. A. & Griffiths, R. E. 1995, ApJ, 453, 48

??rei, Z., Guhathakurta, P., Gunn, J., Tyson, J. A., 1996, AJ, 111, 174

??iavalisco, M., Steidel, C. C., & Macchetto, F. 1996, ApJ, in press.

??eisler, D., Lee, M. G., & Kim, E. 1996 (preprint)

??lazebrook, K., Ellis, R., Santiago, B. & Griffiths, R. 1995, MNRAS, 275, L19

??riffiths, R. F. et al. 1994, ApJ, 437, 67

??organ, W. W. 1958, PASP, 70, 364

??hapley, H. & Ames, A. 1932, Harvard Ann. Vol. 88, No. 2

??teidel, C. C., Giavalisco, M., Pettini, M., Dickinson, M. & Adelberger, K. 1996, ApJ in press.

??oomre, A. 1977, in The Evolution of Galaxies and of Stellar Populations, Eds. B.M. Tinsley and R.B. Larson, (New Haven: Yale Observatory) p. 401

??an den Bergh, S. 1960a, ApJ, 131, 215

??an den Bergh, S. 1960b, ApJ, 131, 558

??an den Bergh, S. 1960c, Publ. David Dunlap Obs., 2, 159

??an den Bergh, S. 1982, PASP, 94, 459

??an den Bergh, S. 1990, in Dynamics and Interactions of Galaxies, Ed. R. Wielen (Berlin: Springer), p. 492

??an den Bergh, S. et al. 1996, in preparation

??illiams, R. E. et al. 1996 in Science with the Hubble Space Telescope - II, Eds. P. Benvenuti, F.D. Macchetto & E.J. Schreier (Baltimore: STScI)

Figure Captions

Fig. 1.— Montage showing high-z candidates in the HDF, selected by the color criterion of $U - B > -0.2$ and $V - I < 0.6$. Galaxies are displayed along six rows, sorted by magnitude left to right, starting from the brightest galaxies in the top row. **(Row 1:)** HDF 2-301, HDF 4-341, HDF 2-243, HDF 3-367, HDF 3-589, HDF 4-625, HDF 2-380. **(Row 2:)** HDF 4-184, HDF 4-235, HDF 2-513, HDF 4-7, HDF 4-387, HDF 2-33, HDF 3-56. **(Row 3:)** HDF 2-242, HDF 2-131, HDF 2-555, HDF 3-278, HDF 2-514, HDF 2-275, HDF 2-353. **(Row 4:)** HDF 4-313, HDF 3-617, HDF 2-25, HDF 3-379, HDF 4-372, HDF 2-302, HDF 2-193. **(Row 5:)** HDF 2-356, HDF 2-221, HDF 4-227, HDF 2-351, HDF 4-33, HDF 4-165, HDF 4-59. **(Row 6:)** HDF 3-616, HDF 4-308, HDF 4-368, HDF 2-459, HDF 2-526, HDF 3-267, HDF 4-655.

Fig. 2.— Example of a "tadpole" (head-tail) galaxy (HDF 2-234). Most objects of this type are blue indicating that their light is dominated by young stars.

Fig. 3.— Example of a possible protospiral (HDF 2-86) with an orange nucleus surrounded by blue knots.

Fig. 4.— Example of a multiple merger of compact blue objects (HDF 2-403).

Fig. 5.— Possible proto-spiral with asymmetrically located reddish nucleus embedded in a structure containing blue knots (HDF 3-312).

Fig. 6.— Example of a blue chain of knots (HDF 3-531). Such objects (first reported by Cowie et al. 1995) may be related to "tadpole" galaxies.

Fig. 7.— This is the *only* example of a possible barred spiral in the HDF survey (HDF 4-105). Alternatively this object may be interpreted as a spiral that was distorted by a recent tidal encounter with a compact companion.

Fig. 8.— Montage showing all barred spirals in the Frei *et al.* sample artificially redshifted to $z = 1$. The barred structure of most galaxies remains evident.